the Energy to Lead

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GTI PROJECT NUMBER 20750

Feasibility of Using Plastic Pipe for Ethanol Gathering

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Technical Status / Results – Materials Compatibility and Test Data Literature Search

GTI continued to follow up with the primary resin manufacturers for PE, PP, PVDF, and PA thermoplastics during the 5th Project Quarter. The objective of these communications was to obtain any unpublished/new data or information related to the chemical compatibility of these thermoplastics with ethanol (a Task 3 work activity).

The completed body of work on *Task 3 - Materials Compatibility Analysis* is presented in this (5th) Project Quarterly Report.

Task 4 – *Evaluate Pipe System Material/Products for gathering Applications* has begun with a baseline analysis to determine the minimum pipe performance needed to allow for a gathering system in the "real world." A list of requirements as discussed with Mr. Corr is contained below.

TASK 2 & 3 - Materials Compatibility Analysis (Now Completed – Possible additions if more manufacturers respond with data)

Thermoplastic Piping - Advantages and Limitations to Consider for Use with Ethanol Gathering Networks

Advantages

- Mature ASTM Standards exist for proper short term and long term testing and use of thermoplastics and thermoplastic piping,
- A very competitive industry which offers excellent value to the end user of these products,
- Decades of successful use in many industries, including oil, gas, chemical, etc.,
- Tremendous corrosion resistance in buried environments,
- Outstanding chemical resistance to many chemicals and solvents,
- Easy to lift, cut, join, and install,
- Produced using less energy than metal,
- Flexible (important for underground applications) and tough,
- Outstanding hydraulic (flow) properties, and
- Clear marking and identification via print lines.

Limitations

- Low strength and low stiffness,
- Ability to locate underground (can bury tracer wire with the pipe to overcome this), and
- Sensitivity to high temperatures.

Methods of Joining Thermoplastic Pipe

There are a variety of methods to join thermoplastic pipe. Selection from the possible methods depends on the material of the pipe, the function of the pipe, and the corrodent/material being transported. The joining methods can be divided into two general groups: permanent joint techniques and nonpermanent joint techniques.

Permanent Joint Techniques:

- Solvent Cementing
- Butt Fusion
- Socket Fusion (heat and electro-fusion)

Nonpermanent Joint Techniques:

- Threading
- Flanging
- Bell-ring-gasket joint
- Compression insert joint
- Grooved-end mechanical joint

A brief summary of each method with advantages and disadvantages is provided below and will be useful in later sections of this report.

Solvent Cementing

Used with PVC, CPVC, ABS, and other styrene based materials.

Advantages:

- No special tools,
- Pipe is less expensive,
- Pull-out resistant,
- Many fittings to choose from,
- Pressure resistant up to burst pressure,
- Excellent chemical resistant (i.e., joint is same material),
- No threads to cut, and
- Very easy installation.

Disadvantages:

- Cannot dissemble, and
- Leaky joints hard to repair.

Butt Fusion

This method provides a very strong joint (as strong as or stronger than the pipe). Pipe can be put into service once cooled. Used extensively with PE, PB, PP, and PVDF.

Advantages:

- Pull-out resistant,
- Pressure resistant beyond burst pressure of the pipe, and
- Excellent chemical resistance (i.e., joint is same material).

Disadvantages:

- Cost of fusion equipment,
- Bulkiness of equipment,
- Cannot disassemble the joint, and
- Fusion procedures must be followed carefully.

Socket Fusion

This method is also used for polyolefins such as PE, PB, PP, and PVDF. There are two different methods (a) socket heat joints and (b) electrical-resistance fusion (EF) joints.

EF Socket Fusions

The EF sockets use heat from an electrified copper coil (usually installed/imbedded in the fitting by the manufacturer) to soften the outside surface of the pipe end and the inside surface of the fitting socket. Used commonly with PE in the gas industry and PP in acid waste drainage systems.

Advantages:

- Piping can be "dry fitted" and assembled before permanent joints are made.

Disadvantages:

- Imperfect heat distribution possible which could result in low joint strength and possible corrosion resistance problems,
- Cannot be disassembled,
- Must follow joining instructions carefully, and
- Cumbersome equipment required.

Heat Socket Fusions

These types of fusions are the preferred type of fusions for systems handling corrodents. The method uses an electrically heated tool, which softens the outside surface of the pipe and the inside surface of the fitting. The joint is as strong as the pipe. This method is used on all polyolefins.

Advantages:

- Joint as strong as the pipe,
- Small and inexpensive equipment,
- Pull-out resistant, and
- Excellent chemical resistance.

Disadvantages:

- Need high degree of skill and dexterity to form a good joint, and
- Cannot be disassembled.

Threaded Joints

Used on smaller diameters, usually 4 inches or less. Leakage at the joints can still be a problem.

Advantages:

- Easy disassembly for maintenance.

Disadvantages:

- Reduces MAOP by up to 50%,
- Threaded joints in polyolefins are leak hazards if pressure exceeds 20 psig (due to low modulus of elasticity), and
- Must use heavier wall pipe (more expensive).

Flanging

Flanges are available for most thermoplastic pipe. The flange is affixed to the pipe by any of the other methods listed above.

Advantages:

- Can be used to connect to pumps, equipment, or metallic piping (tie-ins),
- Excellent for temporary piping systems,
- For lines that require periodic disassembly,
- To reduce field labor since joints can be pre-made and bolted together in the field, and
- For remote locations or poor weather (where fusion methods or equipment are difficult to employ).

Disadvantages:

- Must choose proper gasket for corrosion resistance,
- High material and labor costs, and
- Bulky.

Bell-Ring-Gasket Joints

This type of joint is commonly used for underground, pressure-rated PVC piping for water. It can also be used to connect PVC to metal pipe. An elastomeric ring is retained in a groove in the female joint section. The ring becomes compressed as the pipe is inserted into the joint.

Advantages:

- Simple and quick, and
- Reduced labor cost.

Disadvantages:

- Difficult to make leak free, and
- Danger of pull-out (needs anchoring).

Grooved-End Mechanical Joint

The pipe ends are grooved and a metal coupling with an elastomeric seal is fitted over the pipe ends with a bolt and hinge. This joint is used primarily with PVC and CPVC since they are sufficiently rigid to retain the integrity of the grooves.

Advantages:

- Easy field assembly, and
- Can disassemble the joint.

Disadvantage:

- Must find compatible elastomer for corrodent being handled.

Key Thermoplastic Materials/Resins[1]

Thermoplastic pipe is made up of the primary resin (polymer) and various additives. The resin provides the basic/major properties of the component (pipe) made from it. The additives provide special properties desired during fabrication and use.

Commercially Available Thermoplastic Pipe Products (Common Resins)[2]

Thermoplastics have significantly different properties between material classes. To successfully use these materials in the short and long-term, one must understand their physical, mechanical, and chemical properties when exposed to various environments and applications.

The major thermoplastic materials with joining methods and typical applications are listed in Table 1 below.

Table 1. Most Common Thermoplastic Materials (used to make pipe)

Material	Joining Method	Applications
PVC - Polyvinyl Chloride	Solvent cementing, threading, and heat fusion	Drains, vents, waste streams, sewage, casings, and chemical processing
CPVC - Chlorinated Polyvinyl Chloride	Solvent cementing, threading, and heat fusion	High temperature applications
PE - Polyethylene	Heat fusion and mechanical fittings with inserts	Water, corrosive chemicals, natural gas, and electrical conduit
PP - Polypropylene	Heat fusion and threading	Chemical waste, natural gas, and oil field
PA - Polyamide	Heat fusion and mechanical fittings	PA-11 and PA-12 are used to a limited extent for extruded pipe in the natural gas industry (or research applications).
ECTFE - Ethylene Chlorotrifluoroethylene	Butt fusion only	Cryogenic, radiation areas, high wear applications, liners, high-temperature wire and cable insulation, and chemical waste
PVDF - Polyvinylidene fluoride	Threading, fusion, and flanging	Corrosion resistant valves, pipes, packing material, and process equipment
Saran™ - Polyvinylidene Chloride	Threading only	Food process and meat industries (as liner)

PVC - Polyvinyl Chloride

PVC has been in use for over 30 years in the chemical processing, industrial plating, water supply systems, chemical drainage, and irrigation networks. It makes up the majority of the thermoplastic piping market with PE running second.

PVC is an amorphous (non-crystalline) polymer which contains 56.8% chlorine. PVC is stronger and more rigid than other thermoplastic materials. It has a high tensile strength and modulus of elasticity. PVC has the highest Long-Term Hydrostatic Strength (LTHS) at 73°F of any of the major thermoplastics.

There are two principal Types of PVC - I and II. Type I is un-plasticized or rigid PVC and Type II is modified with rubber and is called high-impact, flexible, or non-rigid PVC. Most PVC pipe is of the high-impact type which has a somewhat compromised chemical resistance to Type I.

PVC piping is available in ¼ inch to 16 inch nominal diameter in Schedule 40 and 80 wall thicknesses. There are six SDR standards for PVC (SDR 13.5 through SDR 32.5) and many additional, larger diameters (e.g., up to 24 inch diameter) available.

ASTM D1784 - *Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds* provides a wealth of information related to PVC grades. However, the chemical resistance specifications in this ASTM exposes PVC to Sulfuric Acid (H_2SO_4) and ASTM Oil No. 3 under short term conditions (e.g., up to 30 days of immersion). This type of exposure data is not relevant to long-term ethanol compatibility.

The preferred method of joining PVC pipe is by solvent cementing. For schedule 80 pipe threads can be used. Flanged joints are always an option, as are bell and ring gasket joints (underground water pipe), grooved-end mechanical joints, and simple compression insert joints.

CPVC - Chlorinated Polyvinyl Chloride

CPVC is made by post-chlorination of PVC to increase the chlorine content to approximately 67% and has very similar properties to PVC but withstands higher temperatures (although at a higher cost than PVC). CPVC has been used for 25 years in the chemical process industry and is widely used for "condensate" return lines to move hot water.

As with PVC, the preferred method of joining CPVC pipe is through solvent cementing. Schedule 80 pipe may be threaded if joints will not exceed 150F. Flanges can be used as necessary.

PE - Polyethylene

Although PE is not as strong and rigid as PVC, but its excellent flexibility, ductility, and toughness make it a very good candidate for buried pipelines and conduit. PE is a partially crystalline material. PE has very good chemical resistance and good cold weather properties. It comes in a variety of densities with pressure applications using medium (Type II) and high (Type III) density PE resins. PE pipe is used in the natural gas, mining, industrial, and sewer applications

Typical high density PE pipe is available in ½ inch to 36 inch diameters. It may be used in pressure applications up to 140F (180F in non-pressure applications).

PE pipe is primarily joined by thermal fusion techniques.

Cross-linked PE piping material has higher strength, stiffness, and abrasion/chemical resistance compared to regular PE, especially at higher temperatures (e.g., 200F). Cross linked PE is usually joined with threads.

PP - Polypropylene

PP is a cost effective material that offers excellent physical, chemical, mechanical, and thermal properties. PP has lower impact strength than PE, but higher working temperatures and tensile strengths. Unmodified PP is the lightest weight plastic pipe and generally has some of the best chemical resistance.

Although excellent in chemical resistance to caustics, solvents, acids, and other organic chemicals, it is not recommended for use with oxidizing-type acids, detergents, low-boiling hydrocarbons, alcohols, and some chlorinated organic materials[3].

Polypropylene is produced in schedule 40 and 80. It is available in standard pressure ratings of 45, 90, and 150 psi. The 150 psi rated pipe is available in ½ inch to 20 inch diameters.

PP can be joined by thermal fusion (preferred method), threading (restricted to schedule 80 pipe), and flanging.

PA - Polyamide[4]

All nylons are polyamides, i.e., polymers that contain an amide group as a recurring part of their chain structure. There are many monomers for nylons and can include linear (aliphatic), side groups, and ring-containing members.

For potential ethanol transport there are two types of polyamide that are produced in pipe form:

- Polyamide 11 (PA11) or Poly[imino(1-oxo-1,11-undecanediyl)] with Castor Oil used as the source monomer, and
- Polyamide 12 (PA12) or Poly[imino(1-oxo-1,12-dodecanediyl)] with Butadiene as its source monomer.

Only PA-11 and PA-12 are distributed on a large scale as plasticized resins for required flexibility.

PA-11 has been used for many years in the extrusion of flexible, steel-reinforced pipe for offshore petroleum production to connect wellheads to platforms, for crude pumping, and oil field fluid transfer. Natural gas distribution networks have been made from un-plasticized PA-11 for many years. Regions of Australia use PA-11 as the exclusive pipe for natural gas in both small and large diameters. Properties valued are low permeability to methane, high strength, resistance to stress crazing, ease of installation, cold impact strength, and chemical resistance. PA-11 has been recently approved by the U.S. DOT/PHMSA (effective 1/23/2009) for natural gas use up to 200 psig with a design factor of 0.40 for pipe up to 4 inches in diameter.

PA-12 has been used in the automotive industry for tubing for fuel, air brake and other lines. PA-12 has been formed into gas pipe and an extensive testing program has been recently completed to support its use up to a proposed 250 psig with a design factor of 0.40 through 6 inches in diameter. Two special permit has been granted to allow "on-system" installation to serve customers.

Solubility and Solvent Effects - One important property of nylons is their solvent resistance. This is the result of their high crystallinity and strong inter-chain interactions due to hydrogen bonding. Hydrogen bonds are the strongest secondary bond forces (~33kJ/mole). Amorphous regions are more susceptible to attack by solvents than crystalline regions (which have crystal lattice forces to overcome in addition to hydrogen bond forces). Therefore semi-crystalline nylons like PA-11 and PA-12 have better solvent resistance than amorphous nylons like PA-6I/6T.

Alcohols and solvents have strong hydrogen bonding capability and therefore attack amorphous regions of nylons. In general, absorption of solvents by nylons diminishes as the hydrogen bonding capability of the solvent decreases. This can be analyzed semi-quantitatively through the use of solubility parameters.

ECTFE - Ethylene Chlorotrifluoroethylene

ECTFE is an alternating copolymer of ethylene and chlorotrifluoroethylene. It provides excellent chemical resistance and has a wide temperature band for use. ECTFE is a tough material with superior impact strength.

ECTFE piping is available in sizes of 1 inch through 3 inches in an SDR pressure rated system of 160 psi at 68°F. It is joined only by the butt fusion method.

Trade Names: Halar (Solvay Solexis).

PVDF - Polyvinylidene fluoride

PVDF is a crystalline, high molecular weight polymer of vinylidene fluoride containing 50% fluorine. It is very similar in structure to PTFE (but not fully fluorinated). It has a high tensile strength and is resistant to gas permeation.

PVDF pipe is available in schedule 40 and 80 and two pressure-rated systems (150 and 230 psi). It can be operated continuously at 280°F. Pipe is available in sizes ½ inch through 6 inches in diameter.

PVDF can be joined by threading (schedule 80), fusion welding (preferred), and flanging.

Trade Names: Kynar (Elf Atochem); Solef (Solvay Solexis); Hylar (Solvay Solexis USA); and Super Pro (Asahi/America).

Polyvinylidene Chloride

Saran has limited applications due to its relatively low operating pressure which decreases rapidly as temperature increases above ambient. It is used more often as a liner for steel pipe. Pipe is available only in schedule 80 with diameters of ½ inch to 6 inches.

Saran pipe is joined only by threading.

Trade Names: Saran (DOW).

Thermoplastics / Fluoroplastics - Not Suitable for Use as Ethanol Gathering Lines

The following polymers are not considered for ethanol gathering line use since they are not commonly made in pipe form (i.e., only liners or very small tubing) and/or are cost prohibitive

- **PTFE -** Polytetrafluoroethylene, also known under trade names (Teflon, Halon, Fluon, Hostflon, Polyfon, etc.) - limited to liner use.
- **FEP -** Fluorinated Ethylene Propylene - limited to liner use.
- **PFA -** Perflouoralkoxy - 2 inch diameter or smaller tubing.
- **ETFE -** Ethylene Tetrafluoroethylene - primarily a lining for steel.
- **CTFE -** Chlorotrifluoroethylene - only available as a liner.

Environmental Effects of Solvents on Thermoplastics - General Discussion [5]

Chemical/environmental resistance of plastics is inherently more complex than that of metals for the following reasons:

1. No two families of plastics are exactly alike and the families vary greatly in the number and type of chemicals to which they are vulnerable;
2. Plastics interact with chemical environments by a number of different mechanisms such as: chemical reaction, salvation, absorption (sorption), plasticization, and stress-cracking (environmental stress cracking);
3. Much of the chemical resistance test development has been directed toward non-pressurized, short-time tests for screening environments, particularly for environmental stress-crack resistance. Such tests are usually not helpful in part design, and rarely so in the prediction of service life[6].

Permeability and Swelling

Unlike most metals, plastics are generally permeable to organic chemicals to varying degrees. Because of this, the presence of environmental liquids in a plastic material can have a profound effect on their mechanical properties. The action of sorption may induce plasticization, swelling dissolution, re-crystallization, and leaching of additives in solids, all of which adversely impact mechanical properties.

After a plastic component is exposed to an organic chemical, aggressive molecules may diffuse into the component, leading to plasticization. Swelling of the material results in high stresses, which can cause crazing or cracking.

Qualitatively, it is convenient to use the Flory-Huggins relationship. The basic idea is that likes dissolve likes. A solvent with characteristics similar to that of the plastic may dissolve the plastic[7]. Also, when solvents and polymers have similar polarities, the polymer will dissolve in or be swollen by the solvent. Because longer chains are more entangled, higher molecular weight hinders dissolution. Semi-crystalline polymers are much harder to dissolve than similar amorphous materials. The tightly packed crystalline regions are not easily penetrated because the solvent molecules must overcome the intermolecular attractions. The presence of cross-links prevents dissolution and polymers can only swell in this case.

Crazing and Cracking

As the difference between the solubility parameters approaches 0, the solvent will be the most effective for dissolving the plastic. The solvent uptake by the plastic induces swelling and the swollen material is plasticized. Its mechanical properties are then below those of an un-swollen solid and the elongation at break increases. The critical strain or stress to obtain crazing (or even cracking) of plastics is observed to also be a function of the difference between the solubility parameters of the plastic and the organic agent[8,9]. In a strong swelling agent the glass transition temperature (Tg) of a plastic is greatly reduced and the fibrils in a craze are highly plasticized and cannot withstand external stresses. Cracks can form rapidly, followed by fracture. In a relatively weak swelling agent, plasticization is limited and there is more crazing vs. cracking.

Superimposed Stress for Structural Components and Environmental Stress Cracking

Structural components (e.g., a pressurized pipe) are subjected to loading during their service. The applied stress may affect the sorption kinetics of the solvent and the equilibrium swelling levels, causing both to increase [10,11,12,13]. As the stress increases, the equilibrium solubility increases which decreases the materials resistance to crazing and cracking. If the material has micro-cracks, the local stress around the cracks increase and lead to increased sorption of the solvent and crazing and cracking. If the agent is a weak solvent for the plastic, the addition of stress imparts strain to the material and allows the solvent to penetrate and weaken the polymer. The stress then causes fracture at these weak areas. This is often termed "environmental stress cracking, ESC (or crazing if not as severe)".

Polyethylene (PE). Because PE is semi-crystalline the environmental degradation from solvents is limited to the amorphous regions. The solubility parameter of PE is 35 $(J/cm^3)^{1/2}$ or 8 $(cal/cm^3)^{1/2}$, and the most widely used ESC agent is nonylphenoxpoly(ethyleneoxy)ethanol (trade name Igepal) which is a surfactant and has a solubility parameter of 40.8 $(J/cm^3)^{1/2}$ or 9.75 $(cal/cm^3)^{1/2}$. Igepal does not swell the PE but under stress it "opens up" enough of the amorphous region to lead to stress-induced plasticization. This same process has been reported in various alcohols[14]. It was also noted that the ESC failure in Igepal, which has a surface tension higher than that of any of the alcohols used in the noted research, occurs as rapidly as that in methyl and ethyl alcohol (ethanol).

The Handbook of PE Pipe[15] details how to consider PE pipe for applications with various chemicals. Preliminary measures of the potential effect of a medium on the properties of PE are by the "soak" or "chemical immersion" test without stressing the material. Strips of PE are soaked for a period of time (usually less than a month) at a specified temperature. After the soaking changes in dimensions, weight, and strength (generally tensile strength and elongation at break) are measured. These types of results [this type of data is summarized and presented in the next section of this report, *Ethyl Alcohol Chemical Resistance Data*] are useful as a guide for non-pressurized applications (e.g., sewer or drainage pipe) where the pipe has minimal stress imposed on it. These types of tests are not applicable to long-term exposure of PE or other thermoplastics to solvents when they are used in pressurized applications. When this is the case, specialized testing is prudent and the use of de-rating factors is common.

PE Material Optimization against ESC [16,17,18,19,20,21]- As noted earlier, PE materials that contain relatively few tie molecules are more susceptible to ESC. Materials with more tie molecules are more resistant to this type of failure. As molecular weight increases, generally the tie molecule concentration increases. Because melt index is inversely proportional to molecular weight, it is desirable to have a material that has a low melt index. Through the optimal use of co-monomers, the resistance of PE to ESC has improved greatly in recent years. An ASTM standard [ASTM F1248: "Standard Test Method for Determination of Environmental Stress Crack Resistance (ESCR) of Polyethylene Pipe")] was withdrawn in 2007 because the committee determined the slow crack resistant test PENT was sufficient. The Handbook of PE Pipe[22] also notes for surface active agents (e.g., detergents), alcohols, and glycols (including anti-freeze solutions) – **If these agents may be present in the fluid a precautionary measure is to specify PE pipe which is made from a material which exhibits very high resistance to slow crack growth (e.g., materials for which the second number in their standard designation code is either 6 or 7, such as PE2708, PE3608, PE3708, PE3710, PE4608, PE4708 and PE4710). For such materials no de-rating is needed."**

Hydrogen Bond Destruction

Some organic acids can disrupt hydrogen bonding between the large macro-molecular chains in bulk polymers. Solvent molecules can form a new hydrogen bond between the solvent and the polymer molecules. This leads to a dissolution process of the material. Polyamides (nylons) can be included in this class of materials since formic acid or phenols can promote stress cracking[23].

Solvent Leaching of Additives

Additives such as plasticizers, fillers, stabilizers, and colorants are introduced into plastics to improve properties. Leaching of these additives may result in deterioration of properties. The chemical resistance of plasticized plastics to organic liquids is usually less than that of un-plasticized plastics.

Key additives used with thermoplastic pipe resins are noted in Table 2 below.

Table 2. Thermoplastic Pipe Additives

Additives	***Purpose***
Antioxidants	Prevent/retard reactions with oxygen and peroxides
Colorants	Color material
Coupling Agents	Improve bonding characteristics
Fillers and Extenders	Reduce cost of high priced resins; improve physical and electrical properties
Heat Stabilizers	Prevent damage from heat and light
Preservatives	To prevent degradation from microorganisms
UV Stabilizers	Slow degradations from sunlight

Adding a plasticizer enhances polymer chain mobility and therefore also enhances the diffusion coefficient of liquids. Organic additives can be extracted from plastics due to solvents and reduce mechanical strength because of the development of a somewhat porous structure in the solid[24].

Ethyl Alcohol (Ethanol) Chemical Resistance Data

The best measure and assurance of chemical resistance comes from many successful applications. Resistance tables are often adequate, although the effects of concentration, temperature, and time and the data on absorption, dimensional change, and change in mechanical properties are limited. If the material is going to be used under pressurized (stressed) conditions, then the data below may not be fully applicable.

From *PPI TR-19/2007* comes a prudent warning of using chemical compatibility tables without restriction:

> *Chemicals that do not normally affect the properties of an unstressed thermoplastic may cause completely different behavior (such as stress cracking) when under thermal or mechanical stress (such as constant internal pressure or frequent thermal or mechanical stress cycles). Unstressed immersion test chemical resistance information is applicable only when the thermoplastic pipe will not be subject to mechanical or thermal stress that is constant or cycles frequently.*
>
> *When the pipe will be subject to a continuous applied mechanical or thermal stress or to combinations of chemicals, testing that duplicates the expected field conditions as closely as possible should be performed on representative samples of the pipe product to properly evaluate plastic pipe for use in this application.*

The following sections are from published compatibility data tables (references are cited). One will note from the data below, several of the published references conflict in their assessment of the compatibility of one or more of the materials with ethanol. In some cases one reference may even classify a material as incompatible with Ethanol while another reference classifies the same material as compatible. The assigned classification for this initial review is based on all the compatibility data collected to date and is taken as a whole.

Note the following color coding (shading) is used in most tables when appropriate:

Green - Positive (desirable) compatibility
Yellow - Moderate or borderline compatibility
Red - Not compatible

A. Corrosion Resistance Tables [25]

Table 3. In Pure Ethyl Alcohol

Material	Temperature Range of Use
PA – Polyamide	Data not available
PE – Polyethylene	60-150F
PP – Polypropylene	60-220F
PVC - Polyvinyl Chloride	60-130F (limited/short term use only)
CPVC - Chlorinated Polyvinyl Chloride	60-200F
ABS - Acrylonitrile-butadiene-styrene	60-130F

Table 4. Chemical Resistance of PA-12 at 23°C[26]

Chemical (Concentration %)	Rating
Acetic acid (10)	2
Acetaldehyd (40)	1
Acetone (100)	1
Butanol (100)	1
Carbon Tetrachloride (100)	2
Diesel oil (100)	1
Ethanol (96)	1
Formic Acid (10)	3
Gasoline, unleaded (100)	1
Heptane (100)	1
Hydrogen Peroxide (2)	2
Methylene Chloride (100)	3
Perchloroethylene (100)	2
Phenol (75)	3
Potassium Hydroxide (10)	1
Sulfuric Acid (10)	2
Toluene (100)	1

Ratings:

1. Resistant, little or no absorption
2. Limited resistance, absorption causing dimensional changes and slight reduction in properties
3. Considerable absorption and/or attack, limited product life

Note:

The effect of moisture on nylons must always be taken into consideration. This is also true when nylon is exposed to large quantities of organic solvents or substances that may contain relatively small amounts of water.

B. Compatible Polymers[27]

Suitable materials (thermoplastics) for ethanol service: **Polypropylene (PP)**.

Materials (thermoplastics) to **avoid** for ethanol service: **PVC and Polyamides (PA)**.

C. Effects of E20 on Plastic Automotive Fuel System Components[28]

The following are considered suitable materials (qualified for ethanol use) based on acceptance in flex fuel vehicles:

- EVOH - Ethylene vinyl alcohol
- **HDPE - High density polyethylene**
- HTN - Zytel

- LDPE - Low density polyethylene
- **PA-12 - Polyamide 12**
- PA 46 - Polyamide 46
- POM - Polyoxymethyle
- PP - Polypropylene
- PPA - Polyphtalamide
- PPS - Polyphenylene Sulfide
- PTFE - Polyteraflouroethylene.

The following were tested and considered compatible with Fuel C, E10, and/or E20:

- PA6 - Polyamide 6
- PA 66 - Polyamide 66
- PEI - Polyetherimide
- PET - Polyethylene terephthalate.

The following were adversely affected by either: Fuel C, E10, and/or E20:

- PBT - Polybutylene terethalate
- PUR - Polyurethane
- PVC - Polyvinyl chloride (flexible type).

D. Corrosion Resistance Tables[29]

Table 5. In Pure Ethyl Alcohol

Material	Max Temperature (F) Range of Use with Ethyl Alcohol	Min./Max. Temperature(F) Range of Use Ambient and No Corrodent
PA - Polyamide	250F	-60/300
PE - Polyethylene	140F	-60/180
PP - Polypropylene	180F	32/215
ABS - Acrylonitrile-butadiene-styrene	140F	-40/140
PVC - Polyvinyl Chloride	140F	0/140
CPVC - Chlorinated Polyvinyl Chloride	210F	0/180
PUR - Polyurethane	Not Recommended	NA

E. Chemical Resistance of Thermoplastic Piping Materials (TR-19/2007)[30]

Table 6. Chemical Resistance from TR-19/2007

Material	Compatibility
CPVC - Chlorinated Polyvinyl Chloride	C to 140
PP – Polypropylene	140
PVC - Polyvinyl Chloride	140
PE – Polyethylene	140
PVDF - Polyvinylidene fluoride	R to 122
PEX - Cross-linked PE	R to 140
PA-11 – Polyamide	C to 104
ABS - Acrylonitrile-butadiene-styrene	No Data

Resistance Codes

The following code is used in the data table:

Code	Meaning	Typical Result
140	Plastic type is generally resistant to temperature (°F) indicated by code.	Swelling < 3% or weight loss < 0.5% and elongation at break not significantly changed.
R to 73	Plastic type is generally resistant to temperature (°F) indicated by code and may have limited resistance at higher temperatures.	Swelling < 3% or weight loss < 0.5% and elongation at break not significantly changed.
C to 73	Plastic type has limited resistance to temperature (°F) indicated by code and may be suitable for some conditions.	Swelling 3-8% or weight loss 0.5-5% and/or elongation at break decreased by < 50%.
N	Plastic type is not resistant.	Swelling > 8% or weight loss > 5% and/or elongation at break decreased by > 50%.
—	Data not available.	

Summary of Initial Compatibility Screening of Thermoplastic Materials that are Currently Available in Pipe Form for Ethanol Use*

*This is a preliminary list, subject to change as more information is collected. As noted in the previous section, the term "compatible" is based on non-pressurized (i.e., unstressed) short-term (≤ 30day exposure) tests of the resin materials. **Final compatibility selections/predictions must include sufficient long-term, pressurized testing applicable to the desired field application.**

Only resins that are currently listed in TR-3 are presented below. There may have been additional candidate materials not listed below since they are not listed in the latest revision of TR-3.

GTI is also in the process of contacting a subset of these manufacturers to confirm if they have any additional data/information related to the resin compatibility with ethanol.

Table 7. Compatible Thermoplastic Materials Currently Available in Pipe Form[31]

Pipe Material Designation Code	Companies That Produce The Listed Material (Independent Listings Only)	Material Designation
Polyethylene (PE)		
PE 2708	Borealis AB	BorSafe ME3440
PE 2708	Borealis AB	BorSafe ME3441
PE 2708	Borealis AB	BorSafe ME3444
PE 2708	Chevron Phillips Chemical	MARLEX TR-418P8
PE 2708	Chevron Phillips Chemical	MARLEX TR-418P8D
PE 2708	Dow Chemical Company	CONTINUUM DGDA 2420 YL
PE 2708	Dow Chemical Company	DOWLEX 2344
PE 2708	Formosa Plastics Corporation	HP3902/MDYC-303
PE 2708	Formosa Plastics Corporation	HP3902/PO2107
PE 2708	Formosa Plastics Corporation	HP3902/PO2240
PE 2708	INEOS Olefins & Polymers	K38-20-160
PE 2708	INEOS Olefins & Polymers	TUB 172
PE 2708	NOVA Chemicals Ltd	NOVAPOL HD-2100-U YELLOW
PE 2708	Total Petrochemicals USA	HDPE 3802 B
PE 2708	Total Petrochemicals USA	HDPE 3802 BLUE
PE 2708	Total Petrochemicals USA	HDPE 3802 Y-CF
PE 3708	Borealis AB	BorSafe HE3470-LS
PE 3708	Total Petrochemicals USA	HDPE 3344N
PE 3710	Total Petrochemicals USA	HDPE 3344N/SW2139
PE 4708	Chevron Phillips Chemical	MARLEX H525P8L
PE 4710	Borealis AB	BorSafe HE3490-LS
PE 4710	Borealis AB	BorSafe HE3494-LS
PE 4710	Chevron Phillips Chemical	MARLEX H516
PE 4710	Chevron Phillips Chemical	MARLEX H516C
PE 4710	Chevron Phillips Chemical	MARLEX H525P8F
PE 4710	Chevron Phillips Chemical	MARLEX H525P8H
PE 4710	Chevron Phillips Chemical	MARLEX 9346P8I

Pipe Material Designation Code	Companies That Produce The Listed Material (Independent Listings Only)	Material Designation
PE 4710	Chevron Phillips Chemical	MARLEX 934698H
PE 4710	Chevron Phillips Chemical	MARLEX 9346P8F
PE 4710	Chevron Phillips Chemical	MARLEX 9346P8E
PE 4710	Chevron Phillips Chemical	MARLEX 9346P8
PE 4710	Dow Chemical Company	CONTINUUM DGDA 2481 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDA 2490 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDA 2490 NT
PE 4710	Dow Chemical Company	CONTINUUM DGDA 2492 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDB 2490 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDC 2480 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDC 2480 NT
PE 4710	Dow Chemical Company	CONTINUUM DGDC 2482 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDD 2480 BK
PE 4710	Equistar Chemicals, LP	ALATHON L4904 Black
PE 4710	Equistar Chemicals, LP	ALATHON L5008HP Black
PE 4710	INEOS Olefins & Polymers USA	TUB 121
PE 4710	Total Petrochemicals USA	HDPE XS10 B
PE 4710	Total Petrochemicals USA	HDPE XT10 N/BLK
PE 4710	Total Petrochemicals USA	HDPE XT10N (natural)
Crosslinked Polyethylene (PEX)		
PEX 0008	INEOS Olefins & Polymers USA	XF1513
PEX 1008	None Listed	None Listed
Polyvinylidene Fluoride (PVDF)		
PVDF 2020	Arkema	KYNAR 1000
PVDF 2020	Arkema	KYNAR 740
PVDF 2025	Solvay Solexis	SOLEF 1010
Polyamide (PA)		
PA 32312 (PA11)	Arkema	Rilsan 11
PA 42316 (PA12)	Evonik Degussa	VESTAMID PA12
PA 42316 (PA12)	UBE America	UBESTA 3035

Summary of Resin Manufacturer Feedback Related to Thermoplastic Materials that are Currently Available in Pipe Form for Ethanol Use

GTI contacted the following resin manufacturers regarding their thermoplastic material compatibility with ethanol:

- Borealis
- Solvay Solexis
- Arkema
- DOW
- Equistar
- Evonik

- Formosa
- INEOS
- NOVA
- CP Chem
- Total
- UBE

GTI requested any ethanol compatibility information with each manufacturer's specific resin line as noted in Table 7 above.

This data could be shrink-swell compatibility data, long-term hydrostatic test data, or any other type of qualitative or quantitative test data related to ethanol compatibility with the subject resins. Pressurized (in ethanol), long-term pipe testing data was specifically called out in the request since this type of data would be most applicable to the end use of the pipe product. If the manufacturer had no ethanol specific data, then a request for other alcohol compatibility data with the subject resin was made.

A request was made that if the manufacturer was producing any other resins that might be compatible with ethanol, but were not listed in the draft public project reports to date that were provided, to identify these and provide any helpful data/information to GTI.

Finally, it was requested that if the manufacturer did not have any data/information (or could not share it) then a communication to this effect would be appreciated.

A summary of the information shared by the manufacturers is shown in Table 8 below:

Table 8. Summary of Ethanol/Polymer Compatibility Information Available from Manufacturers Upon Request

Resin Manufacturer	Long-term hydrostatic test data	Other alcohol (i.e., not ethanol) compatibility data	Other resins with ethanol compatibility not listed in the draft report	No additional data available
CP Chem	No	No	No	Shared some compatibility data (non-pressurized) that reinforced literature search to date
Solvay Solexis	Request remade, Response pending			
Equistar	No	No	No	Anecdotal information that HDPE drums have been used for high purity ethanol successfully
DOW	No	No	No	No
Formosa	No	No	No	Expect HP3902 resins to perform similarly to other PE2708 resins
Evonik	No	Yes	No	
Arkema	No	Yes (E85)	No	
UBE	No	No	No	Shared data that reinforced literature search to date

GTI is still waiting on information from the following manufacturers:

- Borealis
- INEOS
- NOVA
- Total

Technical Status / Results - Composite Piping

In general, the composite piping reviewed included systems comprised of a thermoplastic pipe wrapped with a high strength material. This high strength material, usually fibers, is then shielded by an outside layer of thermoplastic. Composite piping has and continues to be used for flow lines, oil and gas production, water disposal and injection, and subsea applications. Some benefits of composites over steel piping include:

- Chemical and corrosion resistance,
- Can be manufactured and ported in long lengths (requiring fewer connections),
- Lightweight, and
- Does not require cathodic protection.

Product literature on eleven (11) thermoplastic piping products used for rehabilitation or replacement of steel pipelines was reviewed. Each was evaluated for their potential use in ethanol transportation based on application, availability, material, size, and pressure. Three (3) products were for rehabilitation of steel only and were removed from consideration. The eight (8) remaining products have been split into two categories based on likeliness to be compatible.

In ranking, preference was given to stainless steel and plastic connectors and PE, PEX, PVDF, and PP liners. Only the materials in direct contact were considered. Permeation has the potential to affect the reinforcement layer. All the composite pipes evaluated can be produced and are available for use in the U.S. though no consideration was given for regulatory concerns associated with using these products. The pressure ratings given for the products were not based on ethanol therefore; manufacturers should be consulted before using these products.

Removed from Consideration

The pipe products removed from consideration were IT3 Multiwall, Primus Line, and Tite Liner. IT3 Multiwall rehabilitates steel pipe by inserting a plastic pipe and cementing the annular space. Primus Line is a multilayer liner that requires installation in an existing pipeline. The Tite Liner product reduces the diameter of PE pipe to pull into an existing line. Although the PE can be a standalone pipe, the Tite Liner product is for rehabilitation.

Table 9. Removed from List

Name	Contact Material	Joining	Size	Pressure
IT3 Multiwall	PE, PVC, PB, FRP	Multiple kinds	2"+	4,000 psi
Primus Line	Thermoplastic TPU elastomers	Resin	5.9-19.6"	350 psi
Tite Liner	HDPE, PE100	Lined Fittings	2-12"	5,000 psi

Potentially Compatible Composites

Airborne -Thermoplastic Composite Flowline (TCF)

Airborne's TCF product consists of fiber reinforced thermoplastic tapes melt-fused onto a thermoplastic liner and protected by a thermoplastic compound. The product features an Integrated Permeation Barrier and is currently in use as an alternative to steel flow lines.

According to the company's website, the ID material could be PE, PP, PA, or PVDF. Joining can be accomplished with stainless steel or welded plastic connectors. TCF is available in the U.S. in 3, 4, or 5" ID at 1500 psi or 2, 3, 4, or 5" ID at 2500 psi.

From correspondence with Airborne, the product has not been used with ethanol but PP would be the recommend internal material.

Flexpipe Systems - Flexpipe

Flexpipe is currently in use in oil and gas gathering, water disposal and injection, and gas transmission. The pipe is spoolable to 6,890 ft and is joined with metallic fittings which can be nickel plated or thermoplastically coated. According to the manufacturer, the inner material layer is HDPE but could be substituted with requalification testing. The manufacturer reports the product is commonly exposed to methanol without issue. The pipe is available in nominal diameters of 2, 3, and 4" at 300, 750, or 1,440 psi.

Wellstream - FlexSteel™

Wellstream's FlexSteel consists of a flexible steel core with an HDPE liner and exterior cover. It is suited to oil and gas gathering, water or fuel transfer lines, and injection lines. The connectors are made from stainless steel and may only have to be installed every 8,858 ft. The FlexSteel product line includes four different pressure limits, 750, 1,000, 1,500, and 2,250 psi. The nominal diameters range from 2-6".

Through correspondence, Wellstream informed GTI that FlexSteel has been investigated for use with ethanol and believe it to be capable though they have not sold it for that purpose. The primary material in contact with the fuel stream would be PE4710/PE100 but Wellstream has experience using PAs, fluoropolymers, PPSs, and TPEs.

Future Pipe Industries – Spoolable Reinforced Composite (SRC)

SRC is manufactured by wrapping either a composite laminate of glass fibers and/or carbon fibers in a cured epoxy over a plastic liner. The pipe is applicable for oil and gas gathering, injection lines, disposal and transmission lines, and saltwater applications. The plastic liner material determines the suitability to a given application. The product names are Cobra (HDPE), Python (PEX), and Boa (PA-11). SRC is available in sizes 1-4" and pressures up to 2,250 psig. Joining is accomplished via ANSI B16.5 Lap Joint Flange.

Smart Pipe Company, Inc - Smart Pipe®

Smart Pipe consists of high strength fibers wrapped onto a thermoplastic pipe and protected by a PE sheath. The pipe features a monitoring system and comes in multiple configurations. According to email correspondence, the inner pipe could be constructed from PE100, HDPE, PA-11, PA-12, Nylon 11, Nylon

12, or DuPont Pipelon 401. The fiber wrap has been constructed with Spectra®, Kevlar®, and E-Glass. Connections can be made with steel or stainless steel connectors though the pipe can be manufactured onsite in lengths up to 50,000 ft. The Smart Pipe product is available in diameters 6-16" at pressures between 125-1,440 psi.

Pipelife - Soluforce®

Soluforce reinforced thermoplastic pipe (RTP) consists of a PE100 inner core reinforced by a fiber or steel tape and coated with PE100. The pipes are delivered on disposable reels in 400m (1,300ft.) lengths. Connections are made by butt fusing the inner layer then electrofusing an inline coupling over the joint. End flanges are made of stainless steel. Soluforce is offered in 4 or 5" ID in three configurations, Light, Classic, and Heavy. The pressure ratings for water in these products are 522, 1300, and 2175 respectively. For oil, they are 377 and 945 for Light and Classic.

Table 10. Summary of Best Candidates for Ethanol Transport

Name	Contact Material	Joining	Size	Pressure
Airborne	PE, PP, PA, PVDF	Welded Plastic or stainless steel connectors	2, 3, 4, 5"	1,500-2,500 psi
Flexpipe	HDPE	Fittings can be nickel plated or thermoplastically coated	2, 3, 4"	300, 750, 1,440 psi
FlexSteel™	HDPE, PE100	SS	3-6"	1,000-3,000 psi
Future Pipe SRC	HDPE, PEX, PA-11	ANSI B16.5 Lap Joint Flange	1-4"	2,250 psi
Smart Pipe	HDPE	Steel but segments are continuous to ~9.5mi	6-16"	125-1,440 psi
Soluforce	PE100	Fusion and Coupling / SS end flange	4, 5"	360, 610

Less Compatible Composites

DeepFlex Inc. - DeepFlex

DeepFlex composites are used for risers and flowlines as well as jumpers and well services. The pipe is constructed from flexible steel and an extruded polymer. Because no information was available to determine the polymer, the DeepFlex product was not included in the above set of candidates. Connections can be made to transition from DeepFlex to ANSI or API. The pipe is available in 2-8" diameters and can sustain pressures up to 10,000 psi.

Fiberspar – Line Pipe

Fiberspar's LinePipe is used in oil and gas production and pumping corrosive fluids. The inside of the pipe is constructed from HDPE or PEX. The pipe is available in nominal diameters between 2 and 6" and pressures of 750, 1,500, and 2,500 psi. The pipe can be installed in continuous lengths of up to 10,000 ft. Joining is achieved by mechanical compression and elastomeric seals. Because the elastomeric material could be one susceptible to degradation from ethanol, LinePipe was not included in the above section.

Table 11. Potential Solutions

Name	Contact Material	Joining	Size	Pressure
DeepFlex	Extruded Polymer	Transition to ANSI or API	2-8"	10,000 psi
LinePipe	HDPE, PEX	Mechanical compression and elastomeric seals	2-6"	750-2500 psi

Table 12. Composite Company Websites

Name	Website
Airborne	http://www.airbornetubulars.com
DeepFlex	http://www.deepflex.com/
Fiberspar LinePipe	http://www.fiberspar.com/
Flexpipe	http://www.flexpipesystems.com/main/home.html
FlexSteel	http://www.wellstream.com/products/onshore/flowlines.php
Future Pipe SRC	http://www.futurepipe.com
IT3 Multiwall	http://www.unisert.com/about.html
Primus Line	http://www.raedlinger.com/Primusline/englisch/index.htm
SET	http://www.enventuregt.com/
Smart Pipe	http://www.smart-pipe.com/
Soluforce	http://www.soluforce.net/
Tite Liner	http://www.unitedpipeline.com/

Technical Status / Results - Fiberglass Piping

Though the list at this point in the project should not be considered all-inclusive, fifteen (15) fiberglass piping products were investigated for use with ethanol. They were rated by likeliness to be compatible with fuel ethanol. The rating system is from 1-Cannot be used to 4 - Can be used, where a 3 rating is more likely to be compatible with ethanol than a product rated 2.

Three products received ratings of 4 as they are currently used for piping ethanol and are listed by UL 971 "Nonmetallic Underground Piping for Flammable Liquids." UL 971 demands a compability tests with methanol and ethanol at 100% for a minimum of 270 days with a 50% maximum loss in strength. Additionally, a maximum permeation level if 2 g/m^2/day in a 180 day test. Eleven were assigned a rating of 3 because chemical compatibility data for those products specified compatibility with "Ethyl Alcohol" or "E95-100". The remaining product was rated 2 because there was no evidence to support or disprove compatibility with ethanol.

Fiberglass Piping That Can be Used with Ethanol (Rating = 4)

Dualoy 3000/LCX

This product from Ameron is described as a filament-wound fiberglass reinforced epoxy pipe with integral epoxy liner and exterior coating. The pipe is joined by a bell and spigot taper/taper adhesive-bonded joint. It is a double walled pipe currently in use for underground fuel lines, including ethanol. The pressure ratings appear to be limited by fittings but are 250, 150, and 125 psig for 2, 3, and 4" pipes respectively.

Dualoy 3000/MCX

The Dualoy 3000/MCX differs from the LCX because it lacks the exterior coating. All other listed specifications are the same.

Red Thread IIA

Red Thread IIA is filament wound with amine cured epoxy resins and continuous glass filaments with a resin-rich interior surface. It is listed under UL 971 for use with alcohol-gasoline mixtures of either ethanol or methanol up to and including 100%. Joints are T.A.B.™ (Threaded and Bonded) or Bell and Spigot. The primary pipe is rated to 250 psi and comes in 2-4" diameters. Chemical compatibility charts showed a maximum recommended service temperature of 120°F with ethanol at 95-100%.

Fiberglass Piping that is Potentially Compatible with Ethanol (Rating = 3)

Ameron Bondstrand 2000, 4000, and 7000

Bondstrand systems are filament-wound Glassfiber Reinforced Epoxy (GRE) pipes used for general industrial service, including chemical, water, heating, ventilation, and jet fuel. Joining is accomplished via a quick-lock straight taper adhesive joint with integral pipe stop in bell end. All are available in sizes 1-16" and up to 232 psi. The 4000 series has optional internal liners. The 7000 series is configured to have anti-static properties. The reported chemical compatibility of these pipes to ethyl alcohol gives the maximum service temperature of 180°F for the 2000 and 4000 series and 150°F for the 7000 series.

F-Chem (9)(20)

F-Chem is filament wound with epoxy, vinyl ester or polyester resins and fiberglass roving. It is commonly used for water, brine, caustics, petroleum products, acids and other chemical waste streams. Connection types include: bell and spigot, o-ring, flanged, or butt and wrap. It is available in sizes 1-72" and up to 150 psig. Chemical compatibility charts showed a maximum recommended service temperature of 80°F with E95-100.

Fiberstrong RV

Fiberstrong RV consists of a thermosetting vinyl ester resin, continuous and chopped fiberglass reinforcement with a resin-rich reinforced liner. Connections are made via butt-wrap or a double bell coupling with two Reka' saw-toothed gaskets. It can handle pressures up to 250 psi and is available in 16-158" diameters. Chemical compatibility for Fiberstrong is limited to a maximum service temperature of 100.4°F for ethyl alcohol between 95-100% concentrations.

Green Thread

Green Thread is filament wound with amine cured epoxy resins and fiberglass roving. It is commonly used with dilute acids, caustics and hot brine. Bell and spigot style joints are used. It is available in sizes 1-24" and is rated for 225-450 psi. The maximum recommended service temperature is 120°F for 95-100% ethanol.

RB-2530 RB-1520

Centricast RB 2530 and RB 1520 pipe is centrifugally cast with aromatic amine cured epoxy resins and high strength glass fabric. They are employed in chemical process solutions, hot caustics, solvents, acids, salts and corrosive combinations. Connections are made with straight socket or flanged joints. The pipes are available in sizes ½ - 14" and up to 150 psi. The maximum recommended service temperature is 125°F for 95-100% ethanol.

Red Thread II

Red Thread II is a filament wound with amine cured epoxy resins and fiberglass roving used for piping saltwater, CO_2, crude oil, natural gas, light chemical: salts, solvents and pH 2-13 solutions. It can handle pressures up to 450 psi. The pipe is available in 2-24" diameters. The maximum recommended service temperature is 120°F for 95-100% ethanol.

Wavistrong

Wavistrong is produced from glass fibers, impregnated with an aromatic or cyclo-aliphatic amine-cured epoxy resin. It is utilized in refineries, LNG plants, Petrochemical, power plants, oil fields, and offshore platforms. Joining is described as adhesive, rubber seal, flanged, and laminated. Wavistrong is manufactured in 1-48" diameters and is rated to 450 psi. Chemical compatibility charts recommend ethyl alcohol applications to not exceed 140°F.

Z-Core

Z-Core is centrifugally cast from a premium epoxy resin with proprietary curing agents. Joints can be straight socket or flanged. It is commonly employed for applications involving aggressive solvents such as methylene chloride and acetone or corrosives such as 98% sulfuric acid. It is available in 1-8” sizes and up to 150 psi. E95-100 applications should not exceed 175°F.

Conley

Conley produces fiberglass reinforced plastic and glass fiber reinforced plastic pipes for waste water treatment, solvents, petrochemical, chemical processing, fuels and industrial waste. Pipes are available in sizes 1-30” and up to 250 psi. The maximum recommended service temperature is 180°F for 100% ethyl alcohol for Conley’s epoxy pipe. Conley’s vinyl ester and novolac vinyl pipes have a maximum service temperature 80°F for 100% ethyl alcohol.

Fiberglass Piping with Unknown Compatibility with Ethanol (Rating = 2)

Star® Line Pipe

Star® Line is an aliphatic amine cured epoxy fiberglass pipe. Its primary use is with highly corrosive fluids in oil recovery activities. Joining relies on a Mechanical O-ring (70 durometer nitrile). It can handle pressures up to 450 psi and is manufactured in sizes 2-24”.

Table 13. Summary of Fiberglass Pipes

Name	Rating	Chem. Compat.	Material	Size	Pressure	Joining
Dualoy 3000/LCX	4	Listed UL 971	Filament-wound fiberglass reinforced epoxy pipe with integral epoxy liner and exterior coating	2, 3, 4"	250, 150, 125 (fitting)	Bell and spigot taper/taper adhesive-bonded joint
Dualoy 3000/MCX	4	Listed UL 971	Filament-wound fiberglass reinforced epoxy pipe with integral epoxy liner	2, 3, 4"	250, 150, 125 (fitting)	Bell and spigot taper/taper adhesive-bonded joint
Red Thread IIA	4	Listed UL 971	Filament wound with amine cured epoxy resins and continuous glass filaments with a resin rich interior surface	2 - 4"	250	T.A.B.™ (Threaded and Bonded) or Bell and Spigot
Ameron Bondstrand 2000	3	EA 180°F	Filament-wound Glassfiber Reinforced Epoxy (GRE) pipe	1-16"	232	Quick-Lock straight taper adhesive joint with integral pipe stop in bell end.
Ameron Bondstrand 4000	3	EA 180°F	Filament-wound Glassfiber Reinforced Epoxy (GRE) pipe	1-16"	232	Quick-Lock straight taper adhesive joint with integral pipe stop in bell end.
Ameron Bondstrand 7000	3	EA 150°F	Filament-wound Glassfiber Reinforced Epoxy (GRE) pipe	1-16"	232	Quick-Lock straight taper adhesive joint with integral pipe stop in bell end.
F-Chem	3	E95-100	Filament wound with epoxy, vinyl	1-	150	Bell and Spigot, O-ring,

Name	Rating	Chem. Compat.	Material	Size	Pressure	Joining
(9)(20)		80(3)°F	ester or polyester resins and fiberglass roving	72"		Flanged or Butt & Wrap
Fiberstrong	3	EA 95-100 100.4°F	thermosetting vinyl ester (Novolac Epoxy resin base) resin fiberglass reinforcement	16-158"	250	Butt wrap (lamination) or double bell coupling with two Reka' saw-toothed gaskets
Green Thread	3	E95-100 120°F	Filament wound with amine cured epoxy resins and fiberglass roving	1-24"	225-450	Bell and Spigot
RB-2530 RB-1520	3	E95-100 125°F	Centrifugally cast with aromatic amine cured epoxy resins and high strength glass fabric	1/2-14"	150	Straight Socket or Flanged
Red Thread II	3	E95-100 120°F	Filament wound with amine cured epoxy resins and fiberglass roving	2 - 24"	450	
Wavistrong	3	EA 140°F	glass fibers, impregnated with an aromatic or cyclo-aliphatic amine-cured epoxy resin	1-48"	450	Adhesive, rubber seal, flanged, laminated
Z-Core	3	E95-100 175°F	Centrifugally cast from a premium epoxy resin with proprietary curing agents	1-8"	150	Straight Socket or Flanged
Conley	3	EA 180°F	FRP	1-30"	250	
Star®Line Pipe	2		Aliphatic Amine Cured Epoxy	2-24"	450	Mechanical O-ring (70 durometer nitrile)

Table 14. Fiberglass Company Websites

Name	Website
Ameron Bondstrand 2000	http://www.ameronfpd.com/product.html http://www.ameron-fpg.com/?t=industry&i=140
Ameron Bondstrand 4000	
Ameron Bondstrand 7000	
Conley	http://www.conleyfrp.com/
Dualoy 3000/LCX	http://www.ameron-fpg.com/files/pdf/FP737F.pdf
Dualoy 3000/MCX	http://www.ameron-fpg.com/files/pdf/FP915B.pdf
F-Chem (9)(20)	http://www.smithfiberglass.com/F-chem.htm
Fiberstrong	http://www.futurepipe.com/usa/inner.asp?P_SectionID=28&P_CategoryID=100
Green Thread	http://www.smithfiberglass.com/greenthread.htm
RB-2530 RB-1520	http://www.smithfiberglass.com/centricastrb.htm
Red Thread II	http://www.smithfiberglass.com/Predthread.htm
Red Thread IIA	http://www.smithfiberglass.com/pdf/B2101.pdf http://www.smithfibercast.com/Predthreadf.htm
Star ® Line Pipe	http://www.fiberglasssystems.com/linepipe.html
Wavistrong	http://www.futurepipe.com/usa/inner.asp?txt=small&P_SectionID=28&P_CategoryID=104
Z-Core	http://www.smithfiberglass.com/Z-core.htm

Ethanol Compatibility Data Gaps

As discussed in the general section on ethanol compatibility with different pipe materials there is often no direct testing evidence that mimics the service life of an ethanol pipeline. The following three areas are where little to no direct data could be found.

Long Term Strength Testing With Ethanol

The long term strength of a pipe material is usually calculated by performing sustained pressure tests with air or water at an elevated temperature, such as with ASTM D 2837. However, the introduction of a chemical other than air or water can alter the anticipated long term strength of the pipe. Sound engineering judgment is necessary to determine whether it is appropriate to use the long term strength data from these tests with different chemicals. This determination can be initially based on the chemical compatibility tests discussed in this report. However, these tests are often performed on unstressed resin materials and for a "short" time frame. A negative result in compatibility testing gives a strong indication that a certain constituent will adversely affect a resin. However, absence of negative effects does not indicate with certainty that no strength degradation will occur with long term stressed exposure to a particular chemical.

To better anticipate any strength loss with ethanol exposure, tests that expose a pipe to pressurized ethanol would be appropriate. Tests that determine an "ethanol long term strength" by utilizing ethanol as the test medium in determining the long term strength would be the most appropriate but may not be practical. Physically testing post stressed ethanol exposure materials would provide better information to make a sound engineering judgment.

Permeability Testing at Operating Pressures

Polymer materials in direct contact with ethanol can be susceptible to permeation. The exact rate of ethanol permeation, if any, is important to determine the environmental and cost acceptability of ethanol losses. Tests should be performed on all the pipeline components (fittings, joint, transitions, and the pipe itself) at the anticipated service temperature and pressure.

Erosion Resistance with Ethanol Flow

An ethanol pipeline will operate for an extended period of time with constant flow. This has the potential to slowly erode a pipe's and fittings' inner surfaces. Depending on the rate of erosion, this could lead to increased permeation or premature mechanical failure. The erosion risk is greatest at sharp turns of the pipe line, such as a 90 degree bend. The resistance of a material to this erosion will depend both on its hardness and chemical compatibility with ethanol. To determine any possible effects, a test loop could be created and monitored to evaluate if any erosion occurs and at what rate.

References

1 Willoughby, D.A., Woodson, R.D, Sutherland, R., Plastic Piping Handbook, McGraw-Hill, New York, 2002.
2 Sixsmith, T., Hanselka, R., Handbook of Thermoplastic Piping System Design, Marcel Dekker, Inc., New York 1997.
3 Sixsmith, T., Hanselka, R., Handbook of Thermoplastic Piping System Design, Marcel Dekker, Inc., New York 1997.
4 Kohan, M.I., Nylon Plastics Handbook, Hanser Publishers, New York, 1995.
5 Characterization and Failure Analysis of Plastics, ASM International, Materials Park, OH 2003.
6 Ezrin, M., Plaastics Failure Guide - Cause and Prevention, Hanser Publishers, New York, 1996.
7 Symour, R.B., Plastics vs. Corrosives, John Wiley and Sons, 1982.
8 Kambour, R.P., Environmental Stress Cracking of Thermoplastics, Corrosion fatigue, O.F. Deverauz and R.W. Staehle, Ed., National Association of Corrosion Engineers, 1972.
9 Kambour, R.P., A Review of Crazing and Fracture in Thermoplastics, J. Polym. Sci., D, Macromol. Rev., Vol 7, 1973.
10 Rogers, C. E., Polymer Films as Coatings, Surfaces and Coatings Related to Paper and Wood, Marchessault, R.H. and Skaar, C., Syracuse University Press, 1967.
11 Windle, A.H., Case II Sorption, Polymer Permeability, Comyn, J., Ed., Elsevier, 1985.
12 Gent, A.N., Hypothetical Mechanism of Crazing in Glassy Plastics, J. Mater. Sci., Vol. 5, 1970.
13 Brown, H.R., A Theory of the Environmental Stress Cracking of Polyethylene, Polymer, Vol. 19, 198.
14 Singleton, C.J., Roche, E., and Geil, P.H., Environmental Stress Cracking of Polyethylene, J. Appl. Polym. Sci., Vol 21, 1977.
15 Handbook of PE Pipe, 2nd Ed., Plastics Pipe Institute (PPI), Irving TX
16 Howard, J.B., Stress-Cracking, Crystalline Olefin Polymers, Raff, R.A.V and Doak, K.W., John Wiley and Sons, 1964.
17 Dukes, W.A., The Endurance of Polyethylene Under Constant Tension While Immersed in Igepal, Br. Plast., 1961.
18 Herman, J.N. and Biesengerger, J., Molecular Weight Distribution and Environmental Stress Cracking of Linear Polyethylene, Polym. Eng. Sci., Vol 6, 1966.
19 Hannon, M.J., Microscopic Aspects of Brittle Failure of Polyethylene Below the Yield Stress, J. Appl. Polym. Sci., Vol 18, 1974.
20 Howard, J.B. and Marin, W.M., Effects of Thermal History on Some Properties of Polyethylene, SPE J., Vol 16, 1960.
21 Shanahan, M.E.R., et. al., The Influence of Spherulitic Size of the Environmental Stress Cracking of Low Density Polyethylene, Makromol. Chem., Vol 181, 1980.
22 Handbook of PE Pipe, 2nd Ed., Plastics Pipe Institute (PPI), Irving TX
23 Kambour, R.P., A Review of Crazing and Fracture in Thermoplastics, J. Polym. Sci., D, Macromol. Rev., Vol 7, 1973.
24 Ranby, R. and Rabek, J.F., Environmental Corrosion of Polymers, The effects of Hostile Environments on Coatings and Plastics, ACS Symposium Series 229, American Chemical Society, 1983.
25 P. Schweitzer, Corrosion Resistance Tables, 4th ed., Marcel Dekker, New York, 1996.
26 Watson, S.J., in Kohan, M.I., Nylon Plastics Handbook, Hanser Publishers, New York, 1995.
27 M. Curely, Can Ethanol be Transported in a Multi-Products Pipeline?, Pipeline and Gas Journal, May 2008.
28 B. Jones, G. Mead, and P. Steevens, The Effects of E20 on Plastic Automotive Fuel System Components, Minnesota Center for Automotive Research, Mankato Feb. 2008.
29 P. Schweitzer, Corrosion of Polymers and Elastomers, 2nd ed., CRC Press, New York, 2007.
30 Chemical Resistance of Thermoplastic Piping Materials (TR-19/2007), Plastic Pipe Institute, Irving, TX, 2007.
31 HDB/HDS/SDB/PDB/MRS Listed Materials, PPI Listing of Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe (TR-4/2009), Plastic Pipe Institute, Irving, TX, 2009.

List of Acronyms

Acronym	Description
ANSI	American National Standards Institute
API	American Petroleum Institute
CPVC	Chlorinated Polyvinyl chloride
CTFE	Chlorotrifluoroethylene
E10	Ethanol 10
E20	Ethanol 20
E95	Ethanol 95
ECTFE	Ethylene Chlorotrifluoroethylene
EA	Ethyl Alcohol
ETFE	Ethylene Tetrafluoroethylene
EVOH	Ethylene vinyl alcohol
FEP	Fluorinated Ethylene Propylene
FRP	Fiber Reinforced Plastic
GRE	Glassfiber Reinforced Epoxy
HDPE	High Density Polyethylene
PA	Polyamide
PB	Polybutylene
PBT	Polybutylene terethalate
PE	Polyethylene
PEI	Polyetherimide
PEX	Cross-linked Polyethylene
PET	Polyethylene terephthalate
PFA	Perflouoralkoxy
POM	Polyoxymethyle
PP	Polypropylene
PPA	Polyphtalamide
PPS	Polyphenylene Sulfide
PVC	Polyvinyl chloride
PVDF	Polyvinylidene Fluoride
PTFE	Polytetrafluoroethylene
PUR	Polyurethane
RTP	Reinforced Thermoplastic Pipe
TCF	Thermoplastic Composite Flowline

Task 4 –Evaluate Pipe System Materials/Products for Gathering Applications

To better determine the necessary pipe requirements (sizing, hoop stress, joining, fittings, etc.), a base line system is being established. This system will meet requirements as discussed with Mr. Chuck Corr from ADM (project steering committee member). In this discussion the following criteria were determined:

- **Plant Locations**
  - Great plains states – the Corn Belt
  - Little elevation change expected (for corn based ethanol)
- **Capacity:**
  - Average – 50 million gallons per year
  - Current max per plant: 110 million gallons per year
- **Pipeline Configuration:**
  - Tie 4-5 plants to a final plant/distribution point at a Class 1 railroad
  - Direct feed (1-2) plants 40-50 miles away
  - Indirect feed (2-3) plants to a main pipeline that will then carry the ethanol 70 miles
    - The feeder plants could be 10 miles away from a main line
  - A pipeline of this length will need to cross railroads and roads – these crossings will need to be addressed
  - Possibility of adding plants to the feeder line at a future date – consider a design to allow for increased capacity at a future date (don't maximize the system for current requirements)
- **Stable flow from plant with minor fluctuations – pipeline will operate 24 hours 7 days a week**
- **Ethanol make up**
  - Currently transported ethanol contains 2-5% denaturant (gasoline like hydrocarbons)
  - Could (if system is closed) pump "pure crude ethanol" – no denaturant added
  - Make note if this is of considerable importance
- **Final Pressure**
  - 0 psi to fill tank and boost on the spot is acceptable
  - 10-15 psi would allow for filling of tanks without boosting

These requirements will influence a final selection of materials to allow for both the desired capacity and length. These realistic conditions will determine what pressure any pipeline will need to be operated at to allow for the transportation of the desired amount of ethanol.

Plans for Future Activity

Continue to work Task 4 and Task 5 activities with a focus placed on selecting approximately two (2) thermoplastic pipe and two (2) composite pipe systems as leading candidates to focus the Task 5 (Economic Analysis) efforts on.

Respectfully Submitted,

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End of Report